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A SEARCH FOR ν_τ IN THE 350 GEV WIDE BAND NEUTRINO BEAM AND AN UPPER LIMIT FOR ν_μ OSCILLATION INTO ν_τ

E531 Collaboration

(Presented by T. Kondo)

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A SEARCH FOR ν_τ IN THE 350 GEV WIDE BAND NEUTRINO BEAM AND AN UPPER LIMIT FOR ν_μ OSCILLATION INTO ν_τ

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ABSTRACT

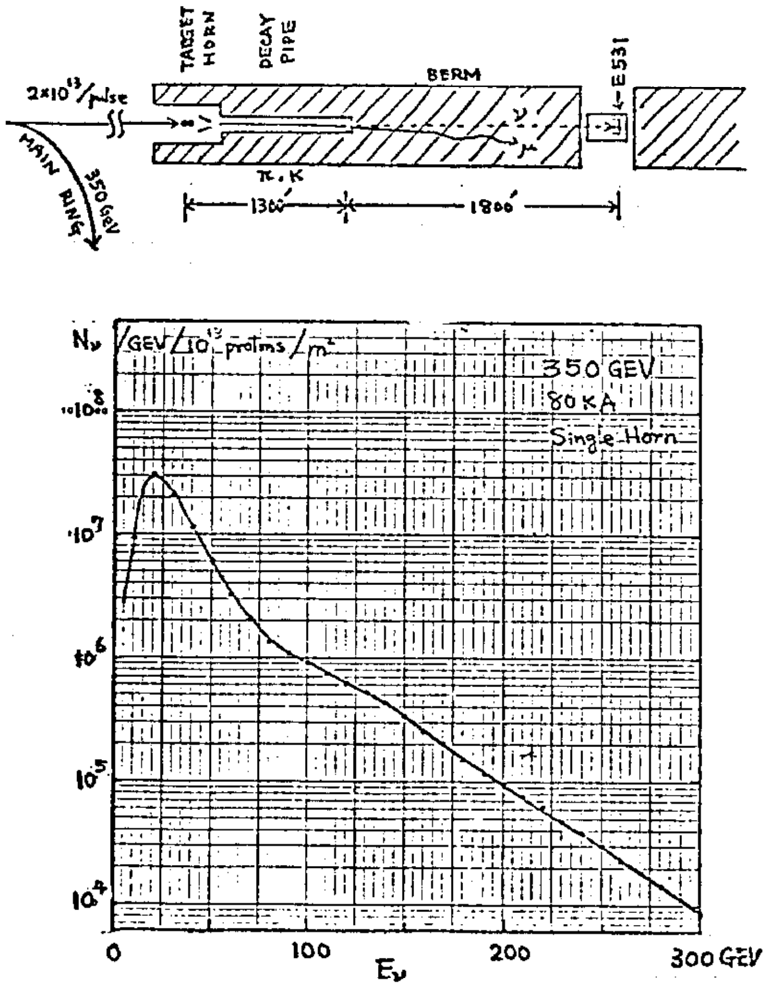
We present a preliminary result on the neutrino oscillation from ν_μ to ν_τ using a hybrid nuclear emulsion detector performed at Fermilab with a wide band neutrino beam. No candidates for τ mesons were found among the secondary products of 885 located (anti-) neutrino interactions. We have set an upper limit of 1.35% (90% CL) for the ν_τ flux relative to ν_μ at the detector. Its implication to the neutrino oscillation is presented. At the maximum mixing between ν_μ and ν_τ, we set an upper limit $\Delta m^2 < 3$ eV^2 (90% CL).

1. SIGNATURE OF τ MESONS

One of the clear signatures of τ mesons is its short lifetime. An experimental upper limit of the lifetime has been placed by DELCO at $\tau_o < 2.3 \times 10^{-12}$ sec (95% CL).[2] Under the assumption of the standard weak interaction theory, we can estimate the lifetime τ_o using the observed pure leptonic branching ratio as

$$\tau_o = \tau_\mu \cdot \left(\frac{m_\mu}{m_\tau}\right)^5 \cdot B_e = (2.72 \pm 0.18) \times 10^{-13} \text{ sec} \qquad (1)$$

where τ_μ = μ lifetime, m_μ = μ mass, m_τ = τ meson mass (1784 ± 4 MeV/c^2) and B_e = branching ratio for $\tau \to e\nu_e\nu_\tau$ (17.0 ± 1.1%). We have assumed that both neutrinos from τ decay are of zero mass in the calculation. Now a 10 GeV τ meson, for example, has a mean decay length of 460 μ. Therefore one sees that the nuclear emulsion is well suited for finding τ mesons in the final states of neutrino interactions.



(a)

(b)

FIGURE 2. (a) Neutrino Beam Line
(b) Neutrino Energy Spectrum

The hybrid spectrometer, shown in Fig. 3 and described elsewhere in detail,[5] consists of 23-liter of Fuji nuclear emulsion target, 20 layers of drift chambers on both sides of a large aperture analysis magnet, time of flight (TOF) hodoscopes for triggers as well as for charged particle identification, an array of 68 lead-glass blocks for electromagnetic showers, a rudimentary hadron calorimeter providing a check on the total hadronic energies, and two banks of muon counters for muon identification. Some of the salient features of this spectrometer are its wide angular acceptance partly because of the usage of the fringe magnetic field for wide angle tracks and its capability of proton identification by TOF up to 6 GeV/c.

Next, three different methods were applied for searching any particle decays among secondaries: (1) tracing all the charged secondary tracks from the interaction vertex to find kink or multi-prong decays, (2) scanning the downstream region to search neutral particle decays into charged prongs, and (3) back-tracing all the charged tracks found in the spectrometer, but with no corresponding tracks observed at the interaction vertex.

Figure 4 shows the decay length distributions of short-lived candidates, grouped into three different decay types: kinks, charged multi-prongs and neutral multi-prongs. The expected mean decay points of 1, 10 and 100 GeV τ mesons are indicated by arrows in the figure. One sees that this experiment is well fitted for the purpose of τ meson search.

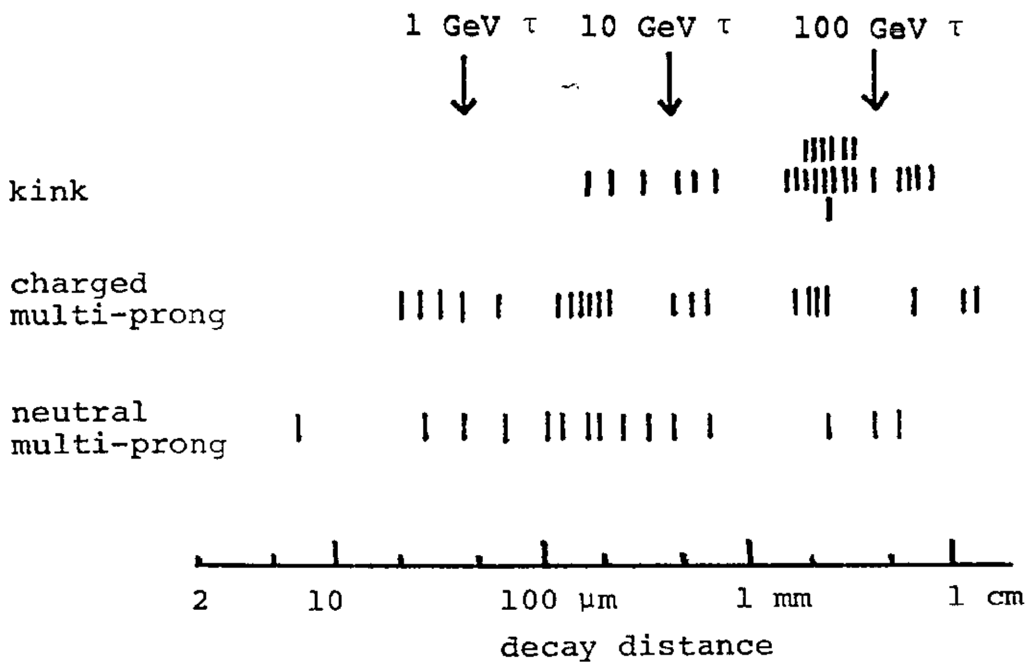


FIGURE 4. Decay length distributions for three different decay types. Arrows are expected mean decay length for τ mesons.

(ionization) and/or $p\beta$ (multiple scattering) in nuclear emulsion, but no events are left for us to apply this criterion.

We set an upper limit of τ interactions relative to charged current ν_μ interactions as

$$\frac{\tau \text{ events}}{\nu_\mu \text{ CC events}} \lesssim \frac{2.3}{700} = 0.0035 \qquad (2)$$

at 90% confidence level.

TABLE III. Cuts for τ Mesons

Successive Cuts	Kink	Charged multi-prong	Neutral multi-prong
	26	19	17
1) charged	26	19	0
2) no baryons in decay products	19	15	0
3) no muons from primary vertex	5	1	0
4) minimum mass $> m_\tau + 2.5\,\sigma_m$	5	0	0
5) $p_\perp > 100$ MeV/c	0	0	0
6) dE/dX and $p\beta$ consistency	0	0	0
Number of τ candidates		0	

5. CORRECTIONS

Two corrections have been applied to evaluate the upper limit of the flux ratio of ν_τ to ν_μ from the observed limit of τ production. (a) ν_τ interaction cross sections: We have used a quark parton model prediction of total cross sections and y distributions,[6] as shown in Fig. 5. (b) Detection efficiencies: Most of the detection efficiencies such as triggering, off-line

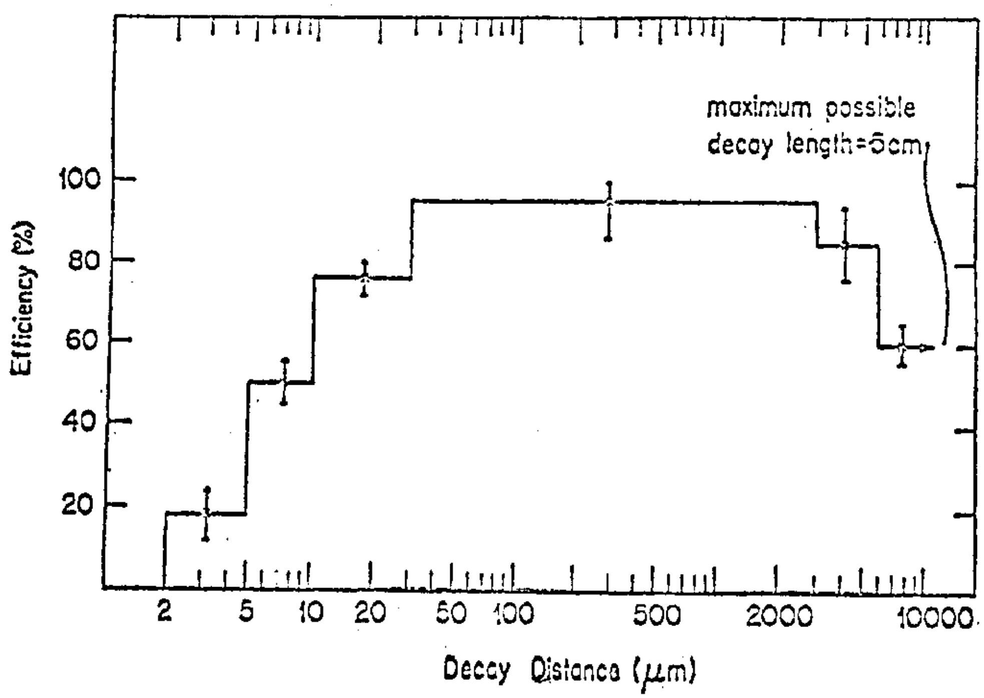


FIGURE 6. Scanning efficiency for charge decaying particle.

These efficiencies are incorporated with the parent neutrino energy spectrum (depicted in Fig. 2) and various decay mode of τ mesons through a simple Monte Carlo simulation. Crudely speaking, the correction factor is given by

$$\left(\frac{\sigma_\mu}{\sigma_\tau}\right) \cdot \frac{1}{B_K \cdot F_K + B_M \cdot F_M} = \frac{1}{0.6} \cdot \frac{1}{0.7 \cdot 0.3 + 0.3 \cdot 0.95} \sim 3.4 \quad (3)$$

where K denotes kinks and M for multi-prongs. The final result using the Monte Carlo correction is

$$R = \frac{\nu_\tau \text{ flux}}{\nu_\mu \text{ flux}} < 1.35\% \quad (90\% \text{ CL}) \qquad (4)$$

at the location of the E531 detector.

A more elaborate calculation involves a double integration over the neutrino energy and the neutrino source point,

$$P(\nu_\mu \to \nu_\tau) = \sin^2(2\alpha)\int dE_\nu \int_0^{\ell_0} d\ell \; \rho(E_\nu) \; \sin^2(1.27 \; \Delta m^2 \frac{\ell}{E_\nu}) < 0.0135$$

where we approximated that the neutrino source point distributes flat in the decay pipe. Figure 8 shows the upper limit (90% CL) in $\Delta m^2 - \sin^2(2\alpha)$ plot.

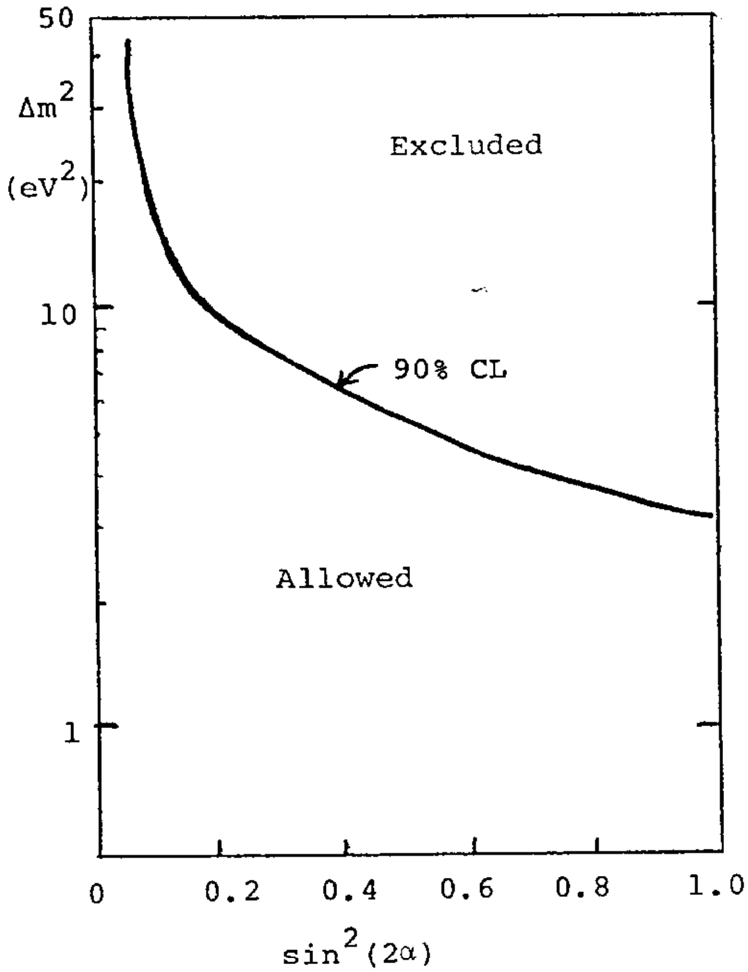


FIGURE 8. Excluded region obtained in this experiment for ν_μ to ν_τ oscillation.

3. C. H. Albright et al., Phys. Lett. 84B, 123 (1979); Phys. Rev. D 20, 2177 (1979).

4. A. M. Cnops et al., Phys. Rev. Lett. 40, 144 (1978).

5. N. Ushida et al., Phys. Rev. Lett. 45, 1049 (1980).

6. K. Bonnardt, Preprint TKP 79-5 (1979).

7. N. Ushida et al., Phys. Rev. Lett. 45, 1053 (1980).

8. The beam dump experiments performed at CERN SPS observed prompt ν_e (or $\bar{\nu}_e$) interactions at the rate of $\sim 1.3/\text{ton}/10^{18}$ protons (H. Wachsmuth, Proceedings of the International Symposium on Lepton and Photon Interactions at High Energies, Fermilab, 1979, p. 541). We assume that these prompt neutrinos come from $D^{\pm}$ and $F^{\pm}$ production is 10% of D mesons due to the presence of a s-quark in F. Using a theoretical estimate of B $(F \to \tau\nu) \sim 3\%$, we obtain the ν_τ event rate in our emulsion target (100 kg),

$$1.3(/\text{ton}/10^{18}) \cdot 0.1 \text{ tons} \cdot 7\text{x}10^{18} \cdot 0.1 \cdot \frac{0.03}{0.2} \cdot 0.6 \cdot 2 = 0.016 \text{ events}$$

where 0.2 is the branching ratio of $D^{\pm} \to e\nu X$, 0.6 is the cross section ratio $\sigma(\nu_\tau)/\sigma(\nu_e)$ and the last factor 2 takes care of the presence of two ν_τ's in the chain decay $F \to \tau\nu_\tau$, $\tau \to \nu_\tau X$. Thus, though this estimate is crude, we are not able to expect any significant prompt ν_τ events in this experiment.